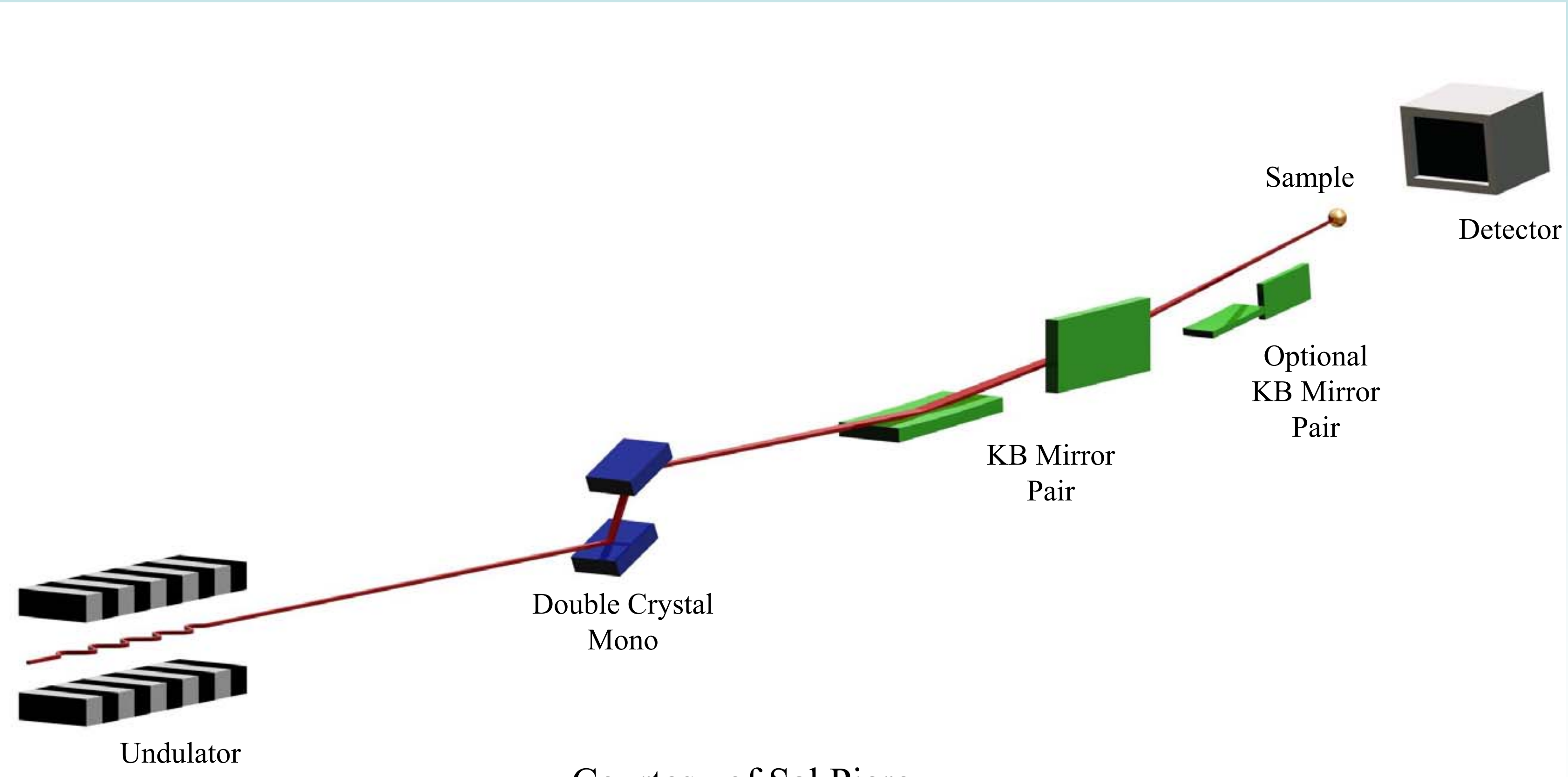
NSLS-II Optics Challenges

Lonny Berman

NSLS, NSLS-II, and PXRR
(in roughly equal measures)

Metrology and Radiology Breakout Session
NSLS-II Powder Diffraction Beamline Workshop
Materials Science & Engineering Planning Workshop
17 January 2008

A conceptual design of a tunable macromolecular crystallography undulator beamline was described in the NSLS-II CDR. It incorporates a cryogenically-cooled double silicon crystal monochromator followed by a K-B focusing mirror system.



Courtesy of Sal Pjerov

The performance of the K-B focusing mirror system was evaluated, particularly the effect of slope error on the focused beam size, using a 1 m long horizontal-focusing mirror and a 0.5 m long vertical-focusing mirror.

Table 11.3.1 NSLS-II Undulator-Based X-Ray Beamline Performance vs. Mirror Figure Error. The red (upper text line in each pair) signifies the "high" demagnification mode for this beamline, and the blue (lower text line) signifies the "low" demagnification mode.

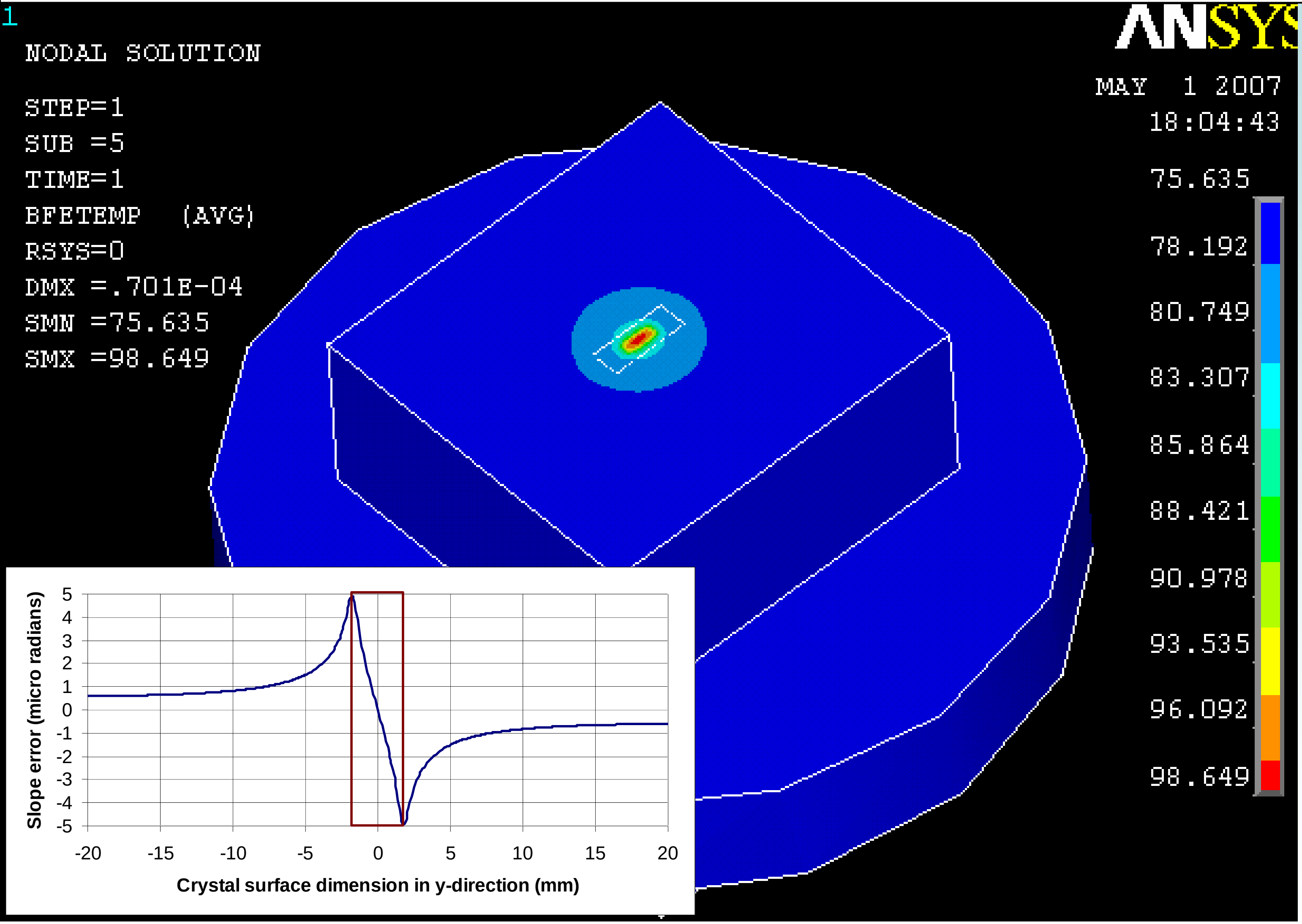
RMS figure error [μrad]	0	0.1	0.5	1.0	2.0
Vertical focus size FWHM [μm]	1.0	2.6	11.8	23.5	47.0
	2.4	6.1	28.3	56.5	112.8
Horizontal focus size FWHM [μm]	15.5	15.8	21.0	32.2	58.5
	33.6	34.2	45.4	69.7	126.7
Monochromatic intensity at 12 keV [ph/s/μm^2]	1.0×10^{13}	4.5×10^{12}	7.9×10^{11}	2.7×10^{11}	7.7×10^{10}
	2.0×10^{12}	8.6×10^{11}	1.5×10^{11}	5.2×10^{10}	1.5×10^{10}

Note: FWHM = Full Width at Half Maximum

~ 2 orders of magnitude reduction in image flux density due to 2 μrad slope error compared with the perfect mirror

Courtesy of James Ablett

Simulations of thermal distortions of the cryogenically-cooled silicon monochromator crystal have also been done.



Simulation of "hockey-puck" liquid nitrogen cooled crystal design using 2σ beam size (1.2 mm wide x 0.75 mm high) from U14 superconducting undulator at maximum K, 30 m distance from source, 12.7º Bragg angle (corresponds to 8.9 keV for Si(111)).

Total power = 109 W (unfiltered), 92 W (filtered)

Maximum temperature = 98 K (unfiltered), 94 K (filtered)

Maximum thermal slope error in beam footprint = ±5 µrad (unfiltered), ±4 µrad (filtered)

Courtesy of Viswanath Ravindranath

And through our simulations for different power loads, we have confirmed the importance of keeping the "hot spot" on the crystal surface at 125 K, to minimize the thermal slope error.

Total Power (W)	Maximum Crystal Temperature (K)	Maximum Thermal Slope Error (μrad)
92	94	±4
109	98	±5
185	125	±1
219	144	±7.4
275	180	±32
326	232	±100

Courtesy of Viswanath Ravindranath

We have also done some simulations using a water-cooled diamond crystal instead of a cryogenically-cooled silicon crystal.

Means of Thermal Contact of Diamond with Copper (Presumed Heat Transfer Coefficient in W/mm^2-°C)	Power Absorbed by Diamond (W)	Maximum Temperature of Diamond (°C)	Maximum Thermal Slope Error (μrad)
Ga-In Eutectic (0.04)	166	267	±30
Brazing (0.4)	166	103	±9

Courtesy of Paul Montanez

Conclusion: pathways to improved performance involve better thermal contact, larger contact area, thinner diamond to absorb less power.

Action Item: watch developments in the field, as the main challenge with diamonds is in obtaining an assured supply of large, good quality crystals.

These simulations have highlighted challenges that are in need of further exploration, and this is embodied in our planned R&D efforts:

(1) sub-micron resolution beam position and profile sensing

(2) thermometry and temperature stabilization of the x-ray beam footprint on the first crystal

(3) adaptive compensation of the distorted wavefront using downstream corrective optics

(4) evaluation of diamond as a substitute for silicon

(5) mirror polishing and metrology (will probably fall under the province of NSLS-II to pursue)